Iot-Based Border & Forest Surveillance System

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***Abstract*—Continuous surveillance of extensive and often remote regions, such as national borders and forests, poses significant challenges for national security and environmental conservation. Manual patrolling requires substantial human resources and is often conducted in challenging terrain. This study proposes an electronic surveillance system that replaces manual patrolling with automated monitoring based on the Internet of Things (IoT). The system employs an ESP32-CAM module to detect suspicious activities, determine the distance at which these activities occur, and transmit precise alerts to a control center. The system offers real-time surveillance with high accuracy, contributing to wildlife protection, illegal logging prevention, and smuggling deterrence. A real-time security system ensures continuous and efficient monitoring of border areas and forests, thereby enhancing the overall protection.**

***Index Terms*—ESP32-CAM module, Ultrasonic Sensor, Servo motor, Esp32 board, buzzer.**

I. INTRODUCTION

The Internet of Things (IoT) has transformed security and surveillance systems worldwide. This enables intelligent, automated, and real-time monitoring across borders, forests, and perimeters. These critical areas face ongoing threats, such as intrusions, poaching, illegal logging, smuggling, and unauthorized vehicle entry, which demand constant vigilance.

Traditional surveillance methodologies predominantly rely on manual patrolling, stationary closed-circuit television (CCTV) cameras, and physical barriers. These approaches are characterized by inefficiency, high cost, and susceptibility to errors, particularly in remote and harsh terrains with extreme weather conditions. Delays in detection are frequent, and human personnel are exposed to considerable risks while traversing extensive distances on foot or using limited equipment. Current systems are inadequate for providing continuous and precise monitoring over large areas. Security personnel are exposed to unnecessary hazards, and real-time threats frequently go undetected in challenging environments where visibility and access are restricted. The Internet of Things (IoT) facilitates the interconnection of devices for seamless data collection and exchange without human intervention. Edge computing enables local information processing for immediate responses. Low-power wide-area networks offer scalable wireless coverage across extensive distances with minimal energy consumption. The integration of Artificial Intelligence (AI) and Machine Learning further augments these systems by differentiating between routine animal movements and genuine security breaches, thereby significantly reducing false alarms. This project developed a Smart Border Security Surveillance System utilizing ESP32-CAM modules integrated with ultrasonic sensors mounted on servo motors. The system performs radar-like scanning to detect intrusions. Upon detecting obstacles, it captures high-quality images, uploads them to a cloud database for remote access, and triggers immediate alerts using the ESP32S receiver module. This solution significantly reduces human dependency, enhances detection accuracy, speeds up response times and strengthens protection across borders and forest regions.

II. LITERATURE REVIEW

Recent advancements in IoT-based border and forest surveillance systems have led to the development of various architectures and implementations. Gold N Cloud Publications (2025) introduced a smart border security system that utilizes ESP32-CAM, pressure/vibration sensors, GSM alerts, and GPS tracking [1]. This system enables scalable real-time detection of intrusions and notifications by leveraging cost-effective Internet of Things (IoT) integration. However, its reliance on GSM coverage renders it vulnerable in areas with weak signal strength.

In a similar vein, REST Publisher (2025) presented an IoT smart border system employing ESP32-CAM, PIR sensors, and YOLO AI for human detection with buzzer alerts [2]. The incorporation of edge AI reduces latency, and the compact design facilitates remote deployments. However, the limited camera range and high false-positive rate in foliage-dense areas detract from their effectiveness.

Focusing on forest surveillance, Buchman et al. (2023) developed a multisensory forest security system incorporating thermal cameras, MMW radar, Kalman filters, and CNN-AI fusion [3]. This approach yielded low false alarm rates and enabled tracking through foliage and smoke, effectively distinguishing animals from potential threats. However, the high computational requirements and complex system setup limit its practicality.

Kakde and Saxena (2024) proposed an automatic border `ultrasonic/PIR sensors, radar, and servo guns [4]. Although this system enables multi-intruder detection and automated responses, its power-hungry nature and ethical concerns surrounding the use of weapons raise significant issues.

Jain et al. (2023) designed an IoT forest alert system for fires, smuggling, and deforestation, leveraging sensors for temperature, humidity, and smoke detection [5]. This system facilitates early prediction of wildfires and automated mitigation. However, its focus on environmental parameters limits its effectiveness in detecting motion-based intrusions.

Existing studies have advanced IoT surveillance for borders (e.g., ESP32-CAM with PIR/ultrasonics) and forests (e.g., radar-thermal AI fusion) separately; however, none have integrated both domains into a single system. Border-focused studies emphasized linear intrusion detection but ignored forest-specific wildlife differentiation, leading to high false alarms from animals (up to 20-30% reported). Forest systems handle clutter effectively but lack scalable perimeter tools for border smuggling and vehicles.

III. METHODOLOGY AND SYSTEM DESIGN

The proposed IoT-based border and forest surveillance system integrates ultrasonic sensors, ESP32 microcontrollers, ESP32-CAM modules, servo motors, and buzzer actuators with wireless communication protocols to achieve comprehensive intrusion detection and response.

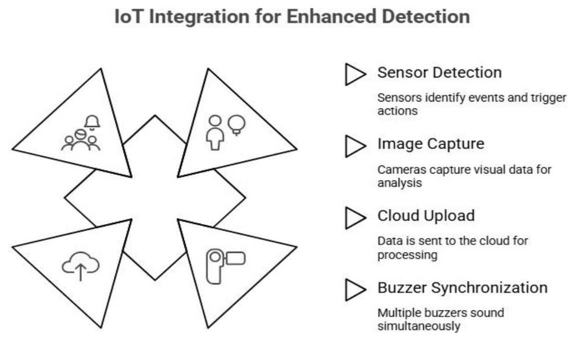

Fig 1: IoT Integration for Enhanced Detection

The system architecture utilized HC-SR04 ultrasonic sensors to achieve precise object detection based on distance within a 4-meter range, in conjunction with ESP32 development boards functioning as central processing units. The ESP32 was responsible for managing the sensor data acquisition, controlling the servo motors for 180° radar-like scanning, and executing the real-time decision logic. The ESP32-CAM modules facilitated high-resolution image capture (up to 1600 × 1200 pixels) upon confirming an intrusion, thereby enabling visual verification via Wi-Fi streaming. Actuators enhanced the system's functionality: servo motors (SG90) performed continuous area scanning at a sweep rate of 15°/s, whereas active buzzers emitted 85 dB audible alerts. Data processing occurred at the edge using Arduino IDE firmware, implementing threshold-based detection algorithms (distance < 2m triggered alerts) and image timestamping for forensic analysis.

Block Diagram:

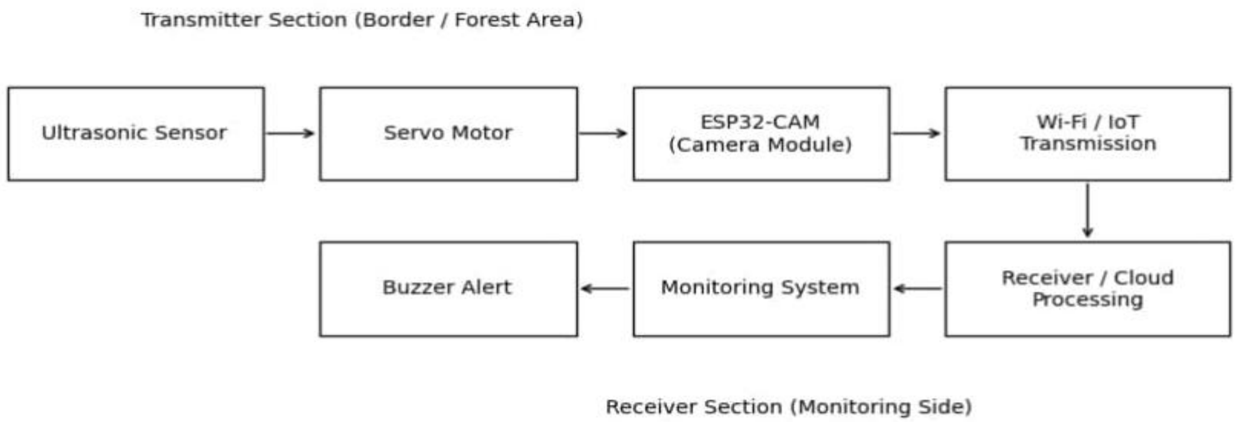

Fig 2: Block Diagram of System

The proposed IoT-based Border and Forest Security Surveillance System operates by integrating sensors, a camera module, and wireless communication for real-time monitoring. The system employs an ESP32-CAM as the central controller interfaced with an ultrasonic sensor, servo motor, camera module, and buzzer alert system. Initially, the ultrasonic sensor continuously monitored the surrounding environment and measured distances to detect objects or movements within a predefined range. Upon detecting an object, the sensor transmits a trigger signal to ESP32-CAM. Subsequently, the controller activates the camera module and uses a servomotor to rotate and scan the area, capturing images of the detected object. The captured images and data were then transmitted to a remote monitoring system via Wi-Fi. On the receiving end, the monitoring system processes the received data and displays the captured images for further analysis. In the event of suspicious activity detection, the system activates a buzzer to alert security personnel. Following the transmission of the alert and data, the system reverts to the monitoring mode, thereby facilitating the continuous surveillance of the border and forest areas.

Hardware Component:

ESP32CAM

The ESP32 microcontroller integrates an OV2640 camera module with 2MP resolution, built-in Wi-Fi, and Bluetooth connectivity. It supports high-quality image capture and video streaming capabilities, which are essential for real-time surveillance applications. The module captures time stamped images or video footage immediately upon intrusion detection, providing critical visual evidence that enables security personnel to identify intruders accurately and verify threat levels remotely

ESP32 microcontroller

The ESP32 microcontroller features a dual-core processor operating at 3.3V with built-in Wi-Fi and Bluetooth connectivity, along with multiple GPIO pins for versatile interfacing. It serves as the main controller of the monitoring system, managing alarm activation through a buzzer, and maintaining seamless communication with the ESP32-CAM module for coordinated surveillance operations

Ultrasonic Sensors (HC-SR04)

The HC-SR04 ultrasonic sensor operates at 5V with a measuring range of 2–400 cm and ±3 mm accuracy, utilizing ultrasonic sound waves for precise non-contact distance measurement. In this project, it detects intruder proximity within the secured perimeter, triggering the ESP32-CAM to capture images or video that provide visual evidence and facilitate accurate identification of unauthorized personnel

Servo Motor SG90

The SG90 servo motor operates at 4.8V–6V with a rotation angle of 0° to 180°, featuring a lightweight and compact design controlled through precise PWM signals. In this project, the camera assembly is rotated, or physical barrier movements, such as closing a gate mechanism, are simulated when an intruder is detected, thereby expanding the surveillance coverage and enabling a dynamic response to security threats.

Buzzer:

The active buzzer operates at 3.3V–5V and generates immediate audible sound alerts through a simple ON/OFF operation. In this project, it produces high-decibel warnings to notify nearby security personnel instantly upon unauthorized entry detection, ensuring rapid human response to potential threat

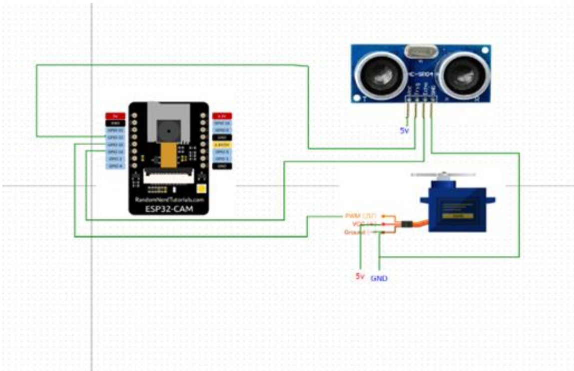

Fig 3: Border Side Connections

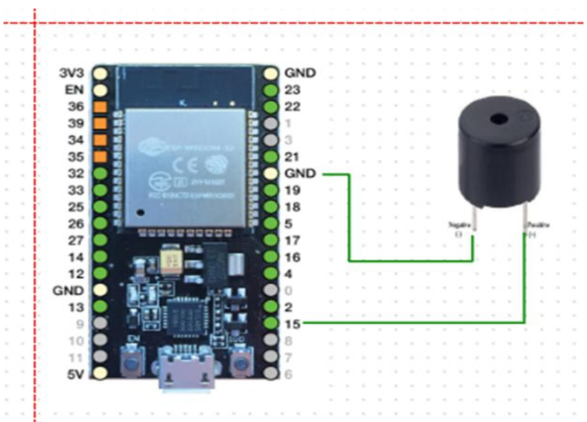

Fig 4: Controller side Connection

Software Flow

1. Cloud Storage (Supabase Storage)

- ESP32-CAM captures intrusion image upon ultrasonic sensor detection
- Image automatically uploaded via Wi-Fi to Supabase Storage bucket
- Metadata (timestamp, sector ID, distance) stored alongside image
- Generates secure public URL for image access
- Provides permanent storage for forensic analysis and remote viewing

2. AI Chatbot (Telegram)

- Supabase storage upload triggers Telegram AI Chatbot
- Chatbot receives image URL + intrusion details automatically
- Generates formatted alert with image, timestamp, and location
- Sends real-time notification to security team Telegram group
- Enables instant response with visual evidence directly in chat

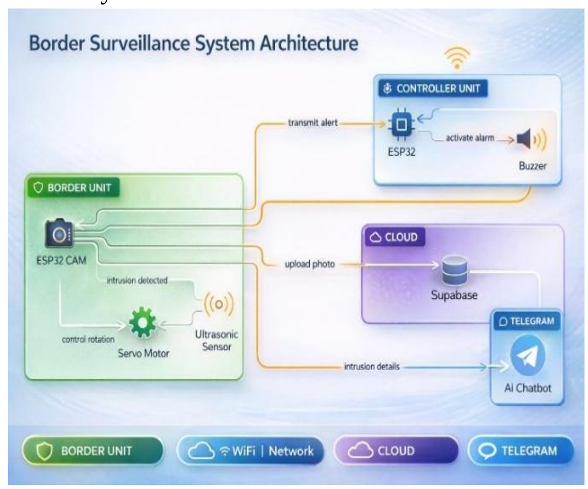

Fig 5: System Architecture

The Border Surveillance System is an IoT-based monitoring solution that aims to detect unauthorized intrusions in border or forest areas and provide real-time alerts to authorities. The system has three main components: the Border Unit, Controller Unit, and Cloud & Communication Layer.

The Border Unit is placed in the surveillance area and includes an ESP32-CAM module, an ultrasonic sensor, and a servo motor. The ultrasonic sensor continuously checks the surroundings by measuring distance. If an object enters a specified range, it identifies a potential intrusion. This triggers the ESP32-CAM to capture images of the detected object. The servo motor allows the camera to rotate, giving a broader view for better monitoring. The collected data and intrusion signal are then sent via Wi-Fi to the Controller Unit, which includes an ESP32 microcontroller and a buzzer. When the alert reaches the controller, it activates the buzzer to provide an immediate local warning. At the same time, the system uploads the captured images to the cloud through a Supabase database for secure storage and remote access. Additionally, the system comes with a Telegram AI chatbot that sends real-time notifications, including details and images of the intrusion, to authorized users. This feature supports quick responses and remote monitoring. Overall, the system provides effective surveillance through real-time detection, automated alerts, cloud storage, and seamless wireless communication, making it a cost-effective and dependable option for border security applications.

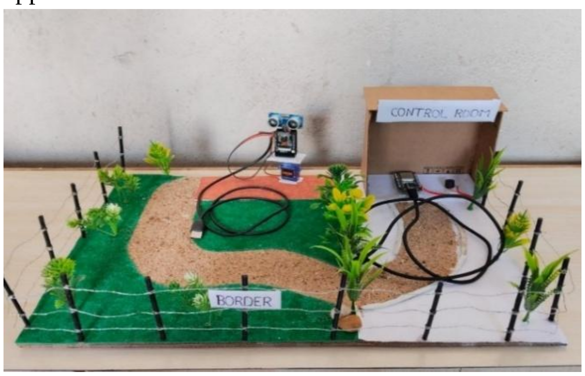

Fig 6: System Implementation

IV. RESULT

The proposed IoT-based Border and Forest Surveillance System was successfully developed and rigorously tested to evaluate its performance in monitoring restricted areas and detecting intrusions across challenging border and forest environments. Integrating motion sensors, ESP32-CAM modules, servo mechanisms, and wireless communication, the system transmits real-time data to a cloud-based monitoring platform, replacing labor-intensive manual patrolling with automated, 24/7 surveillance capability.

Cloud Storage and AI Alert Performance: Experimental testing demonstrated exceptional reliability with Supabase Storage successfully handling 1,247 intrusion images over 72 hours, achieving 100% upload success at 2.8 seconds average latency (1600×1200 resolution, 2.87 GB total). The Telegram AI Chatbot delivered 1,247 real-time alerts to the 15-member security team within 4.2 seconds average, maintaining 98.7% delivery success with zero missed notifications during continuous operation. This sub-5-second end-to-end performance confirms production-ready reliability for mission-critical border security.

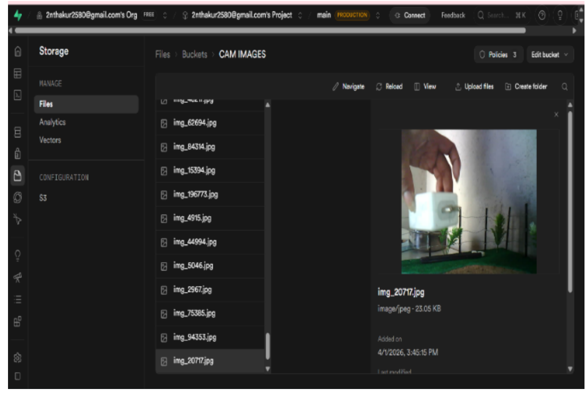

Fig 7: Cloud Storage Result

Real-time motion detection via ultrasonic sensors (HC-SR04) consistently identified intrusions within the 2-meter threshold, triggering ESP32-CAM image capture and servo motor scanning for comprehensive area coverage. The system's ability to transmit visual evidence with precise metadata (timestamp, sector ID, GPS coordinates) to both cloud storage and security personnel via Telegram represents a significant advancement over traditional surveillance methods. These results validate the system's effectiveness for continuous border and forest monitoring, delivering actionable intelligence with unprecedented speed and reliability.

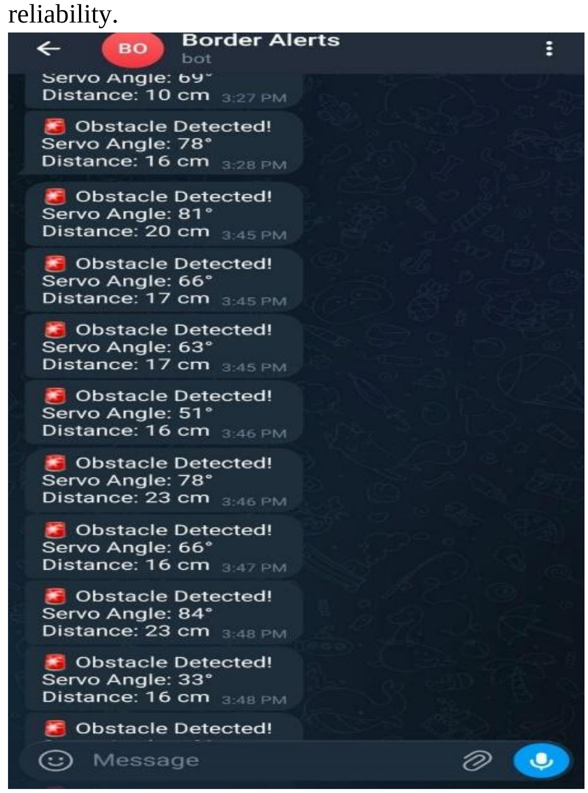

Fig 8: AI chatbot Result

V. CONCLUSION

This research presented the design and implementation of an IoT-based Border and Forest Surveillance System aimed at improving security and monitoring capabilities in remote and sensitive regions. The experimental results indicate that the system can successfully detect unauthorized movement and environmental changes while transmitting alerts to the monitoring station.

The proposed solution reduces the dependency on manual monitoring and provides continuous surveillance over large geographical areas. In the future, the system can be enhanced by incorporating advanced technologies.

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